RB No. L4I07

[redacted]

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

October 1944 as
Restricted Bulletin L4I07

SPINNING OF LARGE AIRPLANES

By Oscar Seidman

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NACA

WASHINGTON

NACA RB No. L4I07

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESTRICTED BULLETIN

SPINNING OF LARGE AIRPLANES

By Oscar Seidman

SUMMARY

Because large airplanes of the transport and bomber categories have been reported to have spun inadvertently, the available information on the subject has been reviewed. Results of model tests, as well as reports of full-scale-airplane spins, were considered. It is concluded that large airplanes should not be intentionally spun because these aircraft are not designed for the loads and speeds that may be encountered in the spin and recovery.

If a large airplane is stalled, either inadvertently or for familiarization purposes, the pilot should apply sufficient down elevator to relieve the stall at the very first sign of stalling. The throttles should be closed if the airplane has started to roll off into a turn and the nose has dropped appreciably. Even after the airplane has rolled off on a wing, the pilot can regain control by promptly moving the stick forward and then using all three controls to return to level flight.

For recovery from fully developed inadvertent spins, the rudder and wheel should be moved against the turn and, about $\frac{1}{2}$ turn later, the control column should be moved forward. In a spin while on instrument flight, the ball bank indicator should not be relied upon to indicate the proper direction in which to move the wheel or rudder, but the rate-of-turn indicator should be used to determine the direction in which to move the rudder and to indicate when the rotation has stopped. The pull-out from the recovery dive should be started promptly to avoid building up excessive speed, but the pilot must be careful not to pull out too rapidly as the airplane might stall again or the structural loads might become excessive. In a spin the pilot would probably encounter difficulty in moving the controls and might have to make use of the tabs and other booster devices; however, he should be careful to avoid overcontrolling after spin recovery.

INTRODUCTION

Pilots who fly large airplanes - that is, transports and bombers - have normally had no experience in spins of such airplanes although these pilots will have been "checked out" in stalls. Their spin training has been obtained on small highly maneuverable airplanes. Large airplanes are not intentionally spun, except on rare occasions, for reasons that will be apparent in the discussion to follow. Relatively little information is generally available, therefore, on spin characteristics of the large aircraft.

Inasmuch as large airplanes have been inadvertently spun or have been in various stages of spin entry, pilots are naturally interested in knowing what to expect if their airplane should get into a spin. The Safety Bureau of the Civil Aeronautics Board therefore requested that the NACA make such information available and the present report was prepared as a result of this request. The information presented herein is considered of interest to both civil and military pilots.

The NACA has obtained a fair amount of data on the spin characteristics from free-spinning tunnel tests of models of large airplanes. The tunnel provides a vertically rising air stream in which the airplane model spins entirely unsupported except by the air forces. After the model has been launched in a fully developed spin, observations are made of the effectiveness of the controls for recovery when they are operated by a remote-controlled mechanical pilot. Most of the discussion of spinning in the present paper is based on results of tunnel tests of about a dozen models. A limited amount of actual flight data has been gathered from pilots' reports and from accident investigations. Pertinent data on pilots' spin experiences have been obtained from aircraft manufacturers, airlines, and the military services.

Although the present report is primarily intended to cover spin characteristics, a brief discussion of stalling is also given. The discussion of stalling is largely based on the experiences of NACA test pilots.

The entire report has benefited from suggestions made by Mr. Melvin N. Gough, Chief Test Pilot of the NACA Langley Memorial Aeronautical Laboratory.

DESIGN FEATURES OF LARGE AIRPLANES

The large airplanes referred to are the present-day conventional monoplane transport, bomber, and multiengine-attack types weighing more than the arbitrarily selected limit of 18,000 pounds. These airplanes are two- or four-engine types. As a result of the installation of engines and other items in the wings, the distribution of mass of these airplanes as a group, as measured by the airplane moments of inertia, is greater along the wings than along the fuselage. The Douglas DC-3 is fairly representative of the class although it has more mass along the fuselage than along the wings. Because of their intended use, all these airplanes are less maneuverable than and are not designed for as high structural strength as the smaller types.

The airplanes for which spin-tunnel-model results were analyzed included 10 twin-engine and 2 four-engine designs ranging in weight from 18,000 pounds to 120,000 pounds. Several of the twin-engine airplanes in the group were of the relatively more maneuverable combat types. All were conventional in appearance although twin-boom tail arrangements were included.

STALL CHARACTERISTICS

Stalling

The subject of stall characteristics is a much broader subject than spinning and has been covered previously in aeronautical literature. The stall characteristics of large airplanes vary widely among different specific designs as do those of smaller airplanes. The stall precedes the entry into a spin. In the worst case, the stall may result in a violent rolling motion of which the pilot receives no advance warning and against which the aileron control is completely ineffective or even detrimental. In most cases the ailerons should not be used. If the control column is not promptly moved forward a sufficient amount to unstall the wing, the wing-dropping may lead to a spiral, a spin, or a falling leaf. In most stalls the aileron effectiveness will be reduced. In better stalls the rolling motion may be less violent and advance notice may be given the pilot in the form of mild buffeting or control shake. For some airplanes no rolling motion is involved and the airplane simply pitches nose down after mild buffeting. An airplane that normally stalls gently may show a violent stall under adverse icing conditions. For most airplanes, the wing-dropping will be more violent with power on than with power off. The stall in the landing condition (gear and flaps down) is frequently milder than in the clean condition although the worst case is almost always for the partial-power, partial-flap, approach condition. If the stall characteristics are good, the experienced pilot can usually make the airplane recover from the stalled condition before the spin actually gets started. NACA test pilots have, in fact, made slowly approached stalls in all types of large aircraft and, although various types of stalls and roll-offs have been encountered, none have been uncontrollable or have gone beyond the very first stages of spin entry.

Spin Entry

Inadvertent spins generally result from stalls that have been followed by a violent dropping of one wing. When the wing loses its lift and drops, the nose of the airplane also drops and the airplane slips in the direction of the low wing. This slipping motion will lead to an air force on the vertical tail tending to turn the airplane off course toward the low wing. This initial turning motion, which gives a change in heading, does not constitute a true spin. Inasmuch as the stall and roll-off is produced solely by the high angle of attack, which is controlled by the elevator, control can still be regained by first unstalling the airplane by use of the elevator and then using rudder and ailerons as available and required to counteract yawing and rolling. If the elevator is moved down more than necessary, the airplane will pick up too much speed. If, however, the pilot fails to check the incipient spin by moving the stick forward promptly, the airplane progressively winds up into a stable spin. The rudder and ailerons will tend to blow with the spin (that is, right pedal forward and wheel to the right in a right spin) and the elevator will tend to blow upward. The number of turns before the airplane gets into a fully developed spin varies with different airplanes; the consensus is that the number of turns is greater than one but less than five. The essential point is that recovery becomes increasingly difficult and requires more turns and altitude loss from the time of the initial stall until the spin steadies down. Recovery should therefore be started as promptly as possible at the very first indication of the stall.

SPIN CHARACTERISTICS OF LARGE AIRPLANES

It has been found that present-day large airplanes have, as a group, certain common spin characteristics:

(1) The spins generally tend to be steep (airplane nose down more than 45° from the horizontal). The airplane may exhibit some tendency for oscillations or, in extreme cases, for a whipping motion during which the attitude varies.

(2) Rates of descent will be high, reaching from 115 to 280 miles per hour (10,100 to 24,600 feet per minute). Inasmuch as the path of descent is almost vertical, these figures also represent the true airspeed. At an altitude of 10,000 feet, a true airspeed of 280 miles per hour is equivalent to an indicated airspeed of 240 miles per hour. The rate of rotation will be relatively low compared with that for small airplanes. The time for one turn will be about 5 seconds for four-engine airplanes and about 2 seconds for twin-engine designs. An average large airplane might, for example, drop 1000 feet at each turn.

(3) As a result of the rotation, the airplane will be subjected to an acceleration of 1.5g to 3g at the center of gravity. Occupants near the center of gravity will be held down by a force of 1.5 to 3 times their weight. The acceleration at the tail might be as much as 6g.

(4) The flattest spins will be obtained when all three controls are deflected fully with the spin. The most rapid recovery will be obtained by reversing all three controls. Moving the control column forward after the rudder has been reversed (that is, moved against the turn) will be very effective for recovery. Moving the wheel against the spin (that is, to the same side that the rudder is moved) will also speed up recovery. In most cases, the turning will have stopped by the time all three controls have been moved as recommended.

(5) Spin characteristics for the landing condition are generally similar to those for the clean condition. If a large airplane spins while coming in for a landing, the chance of completing recovery in the height available is slight.

Little consistent information is available concerning the effects of power (applied symmetrically or asymmetrically) on spins, although it is believed that application of power in a spin may lead to vibration of the structure. Use of power is therefore not recommended in attempting recovery from spins, except as a last resort.

For a number of reasons, spins of large airplanes are dangerous and should not be intentionally entered:

(1) The air load on the airplane in a spin may exceed three times the airplane weight, corresponding to an acceleration of 3g, which is the usual safe structural limit for large airplanes. Oscillations during the spin might so increase the load that danger of local failures or deformations in the structure is encountered. (Fighter airplanes, on the other hand, can safely take an acceleration of 8g.)

(2) The effectiveness of the instruments will be impaired. In a spin the artificial horizon may be inoperative, and the ball bank indicator may not indicate the proper direction in which to move the wheel or rudder. The rate-of-turn indicator should still function properly.

(3) After the airplane stops spinning, it is in a dive and gains speed rapidly. The pilot must pull the airplane out of the dive before the maximum permissible diving speed is reached. Very skillful piloting is required to avoid either pulling up too rapidly, which would impose severe structural loads or even stall the airplane again, or pulling up too slowly and exceeding the safe diving speed. In any case, a considerable loss in altitude would be experienced before the airplane resumed level flight.

(4) All three controls will tend to blow with the spin. Because of the large surfaces and high airspeeds, the controls will be hard to move. The pilot may therefore have to make use of trailing-edge tabs or other booster devices to help in obtaining the desired control movements.

(5) High centrifugal force would affect the crew physiologically and might make it difficult to move the controls or to reach an escape hatch. This effect would be most pronounced near the tail portion of the airplane. A tail gunner probably would not be able to move about.

The small airplane may spin steep or flat. A small airplane rotates faster than a large airplane and has greater rudder effectiveness for recovery. Recovery for small airplanes heavily loaded along the fuselage may be expedited by moving the wheel with the spin. Small airplanes that are heavily loaded along the wings, however, as by multiple wing guns or wing fuel tanks, will have the same elevator and aileron effectiveness as mentioned for large airplanes. Spins of small twin-engine airplanes will resemble those of large airplanes except for the higher rate of rotation of the small airplanes.

Considerable information is available on the spin characteristics of the Douglas DC-3 model and airplane. In appendix A, a detailed description of the model spin characteristics is presented and the effects of different loadings are described. It is shown that if a large airplane happens to be relatively heavily loaded along the fuselage, the favorable effect of moving the wheel against the spin may be lost.

The currently available information on pilots' experiences in spins of large airplanes is summarized in appendix B. These flight experiences are, on the whole, consistent with what would have been expected from model test results.

RECOMMENDED PILOTING PROCEDURE

Reference 1 gives in detail general recommendations for piloting procedure for spinning of pursuit airplanes. With a few exceptions, the general principles specified therein also apply to large airplanes. For inadvertent spins of large airplanes, the following recommendations are made:

(1) The pilot should apply sufficient down elevator to relieve the stall (and increase the speed) at the very first indication of stalling. He must be careful not to apply so much down elevator as to increase the airspeed excessively.

(2) If the stall has occurred with power on, the throttles should be closed when marked rolling has developed and the nose has dropped appreciably. Closing the throttles while the nose is unusually high may result in a whip stall.

(3) If the airplane has rolled off but not yet wound up into a stable spin, the turning motion should be checked by moving the stick forward to unstall the wing and then using all three controls to regain level flight.

(4) After the spin has become fully developed and the controls are with the spin, the most effective control manipulation is to move the rudder against the turn and move the wheel to the same side as the rudder and, about $\frac{1}{2}$ turn later, to move the control column forward as far as appears necessary. These positions of the controls should be held until recovery is effected. Once the airplane begins to respond, the forward movement of the control column should be stopped, inasmuch as this movement noses the airplane down and makes the recovery dive steeper so that the subsequent pull-out takes longer.

(5) In a spin while on instrument flight, the ball bank indicator should not be relied upon to indicate the proper direction in which to move the wheel or rudder, but the rate-of-turn indicator should be used to determine the direction to move the rudder and to indicate when the rotation has stopped.

(6) The dive pull-out should be started as soon as the spin rotation has stopped in order to avoid building up too much speed during the dive. The pilot should not pull out too rapidly as the airplane might stall again or the structural loads might become excessive.

(7) The tabs or other booster devices should be used as much as necessary to obtain the desired movements of the control surfaces. The pilot should be prepared to readjust the tabs upon recovery to avoid overcontrolling in the ensuing dive.

Although spinning of large airplanes has been successfully accomplished in several instances, the evidence points strongly against this practice. Even though the spins may resemble those of some smaller airplanes, the permissible overloads and diving speeds are lower and the controls are much harder to move. Large airplanes are not designed for acrobatics and should not be intentionally spun.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va.

APPENDIX A

SPIN CHARACTERISTICS OF MODEL OF THE DOUGLAS DC-3

Model spin characteristics of the Douglas DC-3 airplane were obtained from tests of a 4-foot-span model in the NACA 20-foot free-spinning tunnel. The specific results in terms of equivalent full-scale data are described in some detail for illustrative purposes.

For the fully developed spin with the elevator up, rudder with the spin, and ailerons neutral, the nose would be down 55° from the horizontal; the rate of descent at an altitude of 10,000 feet would be 117 miles per hour (10,300 feet per minute) and the rate of rotation would be 3.4 seconds for one turn. The acceleration at the center of gravity would be 1.7g. Complete reversal of the rudder alone would give a recovery in 1 turn, after which the airplane would descend in a steep glide. Figure 1 shows the airplane motion during the last turn of the spin and during the recovery. After recovering from such a spin, the airplane would be in a dive at 173 miles per hour true airspeed (152 miles per hour indicated airspeed at 8500 feet). The pilot then would have the alternative of pulling out sharply with resultant high accelerations or pulling out gradually with considerable increase in speed and loss of altitude. If he increased the acceleration to 2g in 2 seconds and held this value during the rest of the pull-out, the airplane would drop 2000 feet during the pull-out to level flight and the speed would have increased to 285 miles per hour true airspeed or 263 miles per hour indicated airspeed. This value of the speed is close to the maximum permissible diving speed for the DC-3 airplane. If the pilot had wanted to use the elevator for recovery, it is estimated that he would have had to push 160 pounds on the control column to start moving it forward. If the pilot managed to get the control column to neutral before reversing the rudder, the spin would be a little flatter and the recovery dive would be steeper than if the control column remained back.

For the model tests in the normal loading condition, the wheel position did not seriously affect recovery. For this loading condition, the model did not show the usual favorable effect of moving the wheel against the spin because, as mentioned earlier, the DC-3 has a relatively heavy load along the fuselage.

Tests of the model in the lightly loaded condition, for which the load distribution was more nearly like that of most other large airplanes, showed a very favorable effect of moving the wheel against the spin and of moving the elevator down. Tests with changes in the center-of-gravity location showed that moving the center of gravity appreciably forward diminished the tendency of the model to spin.

APPENDIX B

FLIGHT TEST RESULTS

Little information is available on intentional spins of large airplanes. Information available on inadvertent spins is of questionable accuracy because of the confusion of pilot and crew, the lack of prepared instrumentation, and the fact that the pilot is concentrating on trying to recover from the spin. This uncertainty in the information should be borne in mind in evaluating the following specific information on full-scale spin experiences.

Douglas DC-3 airplane.- The following instances have been reported concerning spin experiences in the DC-3 airplane (twin engine, 25,550 lb):

(1) A chief pilot for an airline company performed intentional spins with the DC-3 airplane several years ago. The following results were obtained: Three spins were made with wheels up and one with wheels down. All spins were entered at an altitude of 8000 feet. For these tests the airplane weight was only 22,000 pounds. One spin of 2 turns was made with each engine operating at 450 horsepower. There was no effect of power or of landing gear. The longest spin lasted 3 turns. All the time the airplane was spinning, considerable force was necessary to hold the ailerons in the neutral position and there was a very marked buffeting of the tail surfaces. The nose was well down, not being more than 15° from the vertical. No trouble was experienced in bringing the airplane out of the spin; it was necessary only to neutralize the controls after which the spin stopped in less than $\frac{1}{2}$ turn. The maximum indicated airspeed noticed during the spin was 150 miles per hour. On recovery the airplane attained an indicated airspeed of approximately 200 miles per hour. In making three turns, the airplane lost approximately 3000 feet of altitude from the time that the spin was entered until recovery was completed and the airplane was in level flight.

(2) Other instances have been reported where difficulty was encountered. In one instance the spin was

entered accidentally with wheels and flaps down and with partial power. The flaps were retracted and the power reduced. An attempt to stop the spin with the rudder brought no results. Full power was applied to the inboard engine with no effect. The rudder was then neutralized and the control column pushed forward with considerable force at which time the spin stopped.

(3) Several pilots have reported going into 2-turn spins in bad weather or during training maneuvers. The pilots indicate that the ailerons whip toward the direction of spin as the airplane enters the spin. Recovery was generally successfully accomplished by neutralizing or reversing all the controls. A 3-turn spin has been reported during which the nose was 45° down. The loss in altitude during a 1-turn spin and pull-out from the ensuing dive has been reported as 3000 feet.

<u>YFM-1 airplane</u>.- The YFM-1 airplane (twin engine, 18,150 lb) entered a spin inadvertently from an asymmetric-power flight condition. The rudder blew with the spin and the pilot could not push hard enough to move the pedal. The spin was steep. When the co-pilot jumped, he struck and bent the leading edge of the fin and also struck the rudder. At about this time, the pilot found that he was able to move the rudder. The pilot then applied opposite rudder and followed by moving the stick forward and giving opposite aileron, which brought the airplane out of the spin. This spin lasted 19 turns.

<u>B-26 airplane</u>.- A service pilot practicing evasive action stalled a B-26 airplane (twin engine, 26,650 lb) and spun very steeply. He applied controls with the spin for one turn, then gave full opposite rudder, and after one more turn moved the stick forward. When this manipulation had no effect for two turns, he repeated the entire series of control movements; then after two more turns the airplane recovered in a vertical dive. This spin lasted about 7 turns. The co-pilot had closed the throttles after the first turn. The controls were very difficult to move.

<u>P-70 airplane</u>.- Several P-70 airplanes (twin engine, 21,245 lb) have been lost in spins. Details are lacking but it is suspected that high stick forces may have been a contributing factor.

B-17 and B-24 airplanes.- Two four-engine designs, the B-17 (52,000 lb) and the B-24 (50,000 lb) have been reported in spins several times. In some instances serious structural damage and loss of the airplanes resulted. In one case, control forces were reported to be high but the combined efforts of the pilot and co-pilot finally moved the elevator and rudder controls and effected recovery. The spin was steep. A crew member near the middle of the fuselage was able to move about but the tail gunner was unable to move because of centrifugal force.

Boeing 307 airplane.- It is thought that the breaking up of an experimental Boeing 307 airplane (four engine, 42,500 lb) in flight might have occurred during recovery from a dive subsequent to a 2- or 3-turn inadvertent spin.

P-38 airplane.- The P-38 airplane (11,300 lb), which is a small twin-engine design and is similar to some of the large types, has been spun several times. The test pilot reported that on one occasion he was unable to move any of the three controls from their with-the-spin position after a spin of 3 turns. He regained control after eight turns by applying power to both engines.

It would be appreciated if pilots having additional information on actual spin experiences in large airplanes would transmit pertinent data to the National Advisory Committee for Aeronautics at Washington, D. C.

REFERENCE

1. Soulé, H. A., and Seidman, Oscar: Influence of Loading Condition on Piloting Technique for Spin Recovery for Pursuit Airplanes. NACA RB, June 1942.

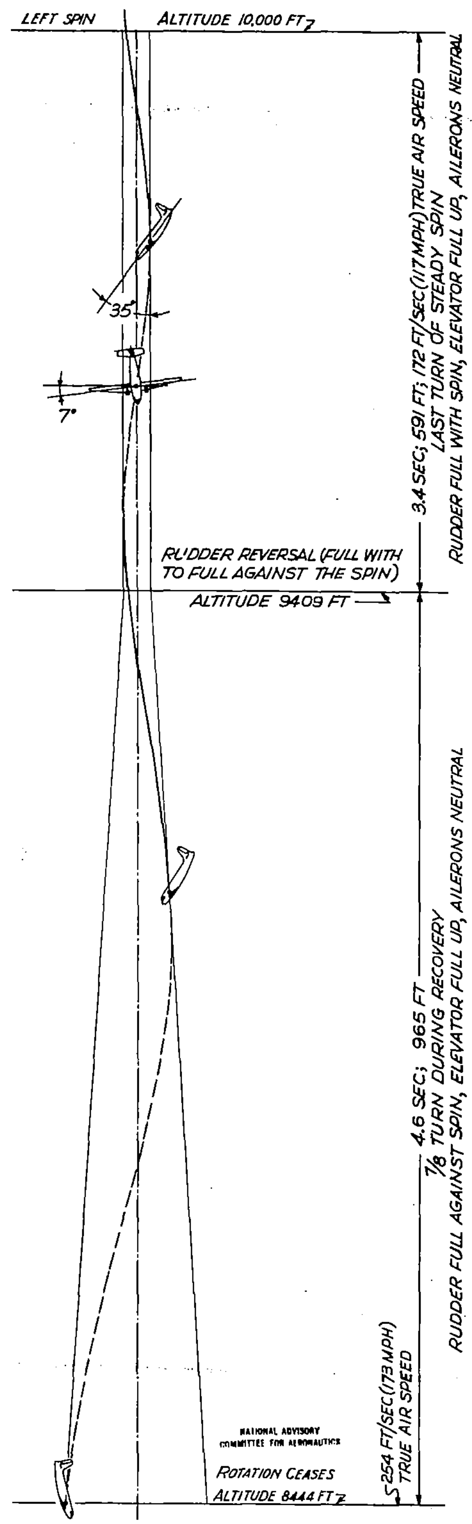

FIGURE 1.- STEADY SPIN AND RECOVERY OF DC-3.